the right of the center do not change abruptly either in speed or direction, and even the sudden shift of wind to the opposite or nearly opposite quarter as the center passes will not account for the suddenness of the rise in many cases. It is difficult to understand how this wind, even though in a sudden and violent onslaught, such as occurs in the cyclone, can in so brief a space drive forward such a mass of water. The storm wave sometimes precedes the shift of wind at the rear of the center, and with this explanation it must be assumed that the wave outruns the wind which produces it.

Cline then assumes that the rise is gradual and that there is no "storm wave" or "tidal wave." Clearly, his explanation of the tide, if accepted as offering the only causes of high water, do not include the causes of a storm wave. Yet the testimony of observers and the fact that hundreds of thousands of persons have been drowned in these overflows, seem to be indubitable evidence that the rise is sudden and overwhelming.

But Cline does not assume that his is a full and complete explanation of the tidal phenomena of the hurricane.

Reasons have been advanced for believing that the waters take on a rotary motion, similar to the winds in the cyclone acting upon the water. These currents will be communicated to great depth, setting enormous masses of water in motion, as evidenced by the movement of buoys anchored in water 40 feet or more in depth. The power of this great rotating mass of water is fearful to contemplate when it is obstructed by the coast line and its accumulations are driven by the cyclonic winds.

Near the center the accumulation of water on the right front is relieved by a swiftly flowing current along shore. This current is suddenly impeded and later reversed as the center of the cyclone moves inland and the rear winds come upon it. With great pressure suddenly thrown against this relieving current as the center leaves the rotating mass, there is cause for a more rapid accumulation on the right of the center. All the waters of the rotary disk tend to pile up on the right of the center against the coast line. Far from the center this is a slow process, but near the center, the shorter the diameter of the whirl and the greater the velocity of the current the more sudden and violent will be the onslaught.

When a bay, inlet, or river mouth lies immediately to the right of the point where the cyclone crosses the coast, this mass of water drives forward into the sloping bed and narrowing channel, to be retarded and heaped up. It finally spills over and sweeps forward. These places are frequently harbors for ships and the locations of cities with a considerable population.

ACKNOWLEDGMENT

The author claims nothing original in the way of observation. He has consulted the writings and observations of Weather Bureau officials recorded mostly in the MONTHLY WEATHER REVIEW and numerous additional sources, but chiefly the works of Cline, Eliot, and Piddington.

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THE RELATION OF SPRING TEMPERATURES TO APPLE YIELDS

By W. A. MATTICE

[Weather Bureau, Washington, October 26, 1927]

Apples, while not of such universal need as corn, wheat, and other important food crops, are still of sufficient value to the human race to have rather large areas of certain States devoted to their cultivation. By examining a dot map prepared by the United States Department of Agriculture, it will be found that the heaviest centers of apple production lie in two States, New York and Washington. No other State has the concentration that is found in these, and between them they produce a large proportion of the Nation's apple supply.

The cultivation of apples requires somewhat different conditions of soil, climate, etc., than most crops. While different varieties of apples require longer or shorter growing seasons, in most cases the local conditions or topography must be favorable if a high-producing orchard is to be maintained. One of the most important risks that confront the apple grower is the liability of damage from late spring frosts. Most apple-producing areas of the United States are exposed to this injury and serious losses occur, but the frost hazard in some sections is comparatively small, particularly in the Northeast. Fruit trees respond readily to relatively short periods of warm weather in spring, and when there are rather long periods of warmth, premature blooming is practically certain. In cases of this kind, the late frosts cause greater damage than when the trees are in a less advanced stage, even though the temperatures may be lower in the latter case.

It has long been well known that the location of an orchard is a vital factor in determining its success. A north slope in some cases has been found to be slightly more favorable than other exposures, due to the retarding effect on blooming and thus reducing the liability of damage by frosts. Orchards in pockets are exposed to harm through air drainage, which will often cause extensive injury to bloom or newly set fruit, while a neighboring orchard on a higher elevation may not be harmed. Spring frosts, the amount of precipitation, the summer temperatures, etc., are elements over which the orchardist has no control, but weather influences can often be controlled or modified through improved orchard management.

The inland river valleys of Washington are peculiarly adapted for apple culture, with their comparatively mild climate and long summers. The southern shore of Lake Ontario in New York State is another region which has been largely devoted to the cultivation of deciduous fruits, with the great body of water acting as a deterrent for spring frosts and otherwise moderating the climate. In other States, Virginia and West Virginia are probably the only ones showing such a concentration of fruit orchards, with the Shenandoah Valley famous for its orchards, and especially for the apple-blossom festival which takes place there every year. Conditions in Virginia, again, are such as to promote apple growing on a large scale, with the great valley affording an extensive area sheltered from many climatic severities.

During the summer of 1926 a survey of the apple-producing sections of Virginia, West Virginia, and Pennsylvania was made by the several State experiment stations and the Department of Agriculture with the cooperation of the Division of Agricultural Meteorology of the Weather Bureau. The purpose of this survey was to determine the economic, geographic, and climatic effects on the apple industry of these three States, and the results show some interesting relations of temperature to the yields of apples.

In the survey, data were obtained for Martinsburg, W. Va., giving the dates of bloom of the York Imperial apple, and also the per cent of a full crop for the years 1911 to 1926. With this material an effort was made to find the day-degree temperature constant for apple blooming at that place. Temperature records are kept at the cooperative Weather Bureau station, and these were used in the study.

In accord with the well-known practice of accumulating temperatures above 43°, various periods of time were chosen, such as January 1 to bloom, February 1 to bloom, and from the blooming date of the previous year to bloom of the next. The accumulations found by these methods were unsatisfactory in that no close relation could be found between the constants, each period having large variations from year to year, as well as from the high to low values, the difference in the latter case sometimes reaching as high as 25 per cent of the maximum accumulation. These results seem in accord with previous findings, as various writers have found objections to the day-degree method. Livingston (1) offered a system of indices based on Lehenbauer's observations of the growth of maize seedlings, but, as these indices are based on an optimum temperature for best growth, more detailed data are needed than were available. It would appear from these studies and from others made by various investigators that the day-degree temperature constant is unreliable, at least when we continue to use the temperature data as usually recorded. Seeley (2) has proposed a widely different method of exposure of the thermometers than usually prevails, and it would seem, in view of all the diverse results obtained, that some other thermal value is necessary to properly obtain plant temperatures. It must be that plant temperatures are the determining factor in growth, for all the work done on constants, using shelter exposed thermometers, is at least variable, as far as obtaining a constant comparable with growth is concerned. It may be that special thermometers will have to be devised, or radical changes made in present methods of exposure, before data showing a constant relation between temperature and periods of plant growth can be found.

There is a close relation between spring temperatures and variations of the blooming date, as warm weather at this season hastens blooming and cooler weather retards it. Records previously obtained had shown a very close relation between the weather during spring and blooming. At Wauseon, Ohio, the period most effective in controlling blooming was found to be March 21 to April 30, but in Virginia the period for which spring temperatures were found to be most effective was from February 7 to March 28. This, however, is in accord with expectations, as the season in Virginia is earlier.

The correlation coefficient between the temperature for this period and yield for Virginia was -0.79 ± 0.05, a very high coefficient for the data used. The yields were those for the whole State, and the temperatures were computed from stations in the great valley and the southwest, where the bulk of the crop is grown.

The relation between apple yields and spring temperatures was so pronounced in Virginia as a whole that the same period was applied to the Martinsburg figures. The result was very gratifying for the coefficient of correlation was -0.85 ± 0.04 against -0.79 ± 0.05 for the whole State.

The influence of the weather during the week of blooming was also studied in an attempt to correlate various elements with yield. In this study, for which Martinsburg blooming dates were used, the results were disappointing. The only element exhibiting a relation to yield was minimum temperature, and even that was too small to be of much significance.

The year 1921 will long be remembered in the apple region of Virginia, for in that year the yield was reduced tremendously. The spring was unusually warm and the apple trees bloomed early, the earliest during the period considered, and while they were in full bloom there was a severe freeze, largely reducing the yield. Full bloom was reported that year about April 10, and freezing weather occurred at almost the same date over the entire region. Temperatures during this cold spell ranged from 23° to 28° throughout the great valley, and the crop was

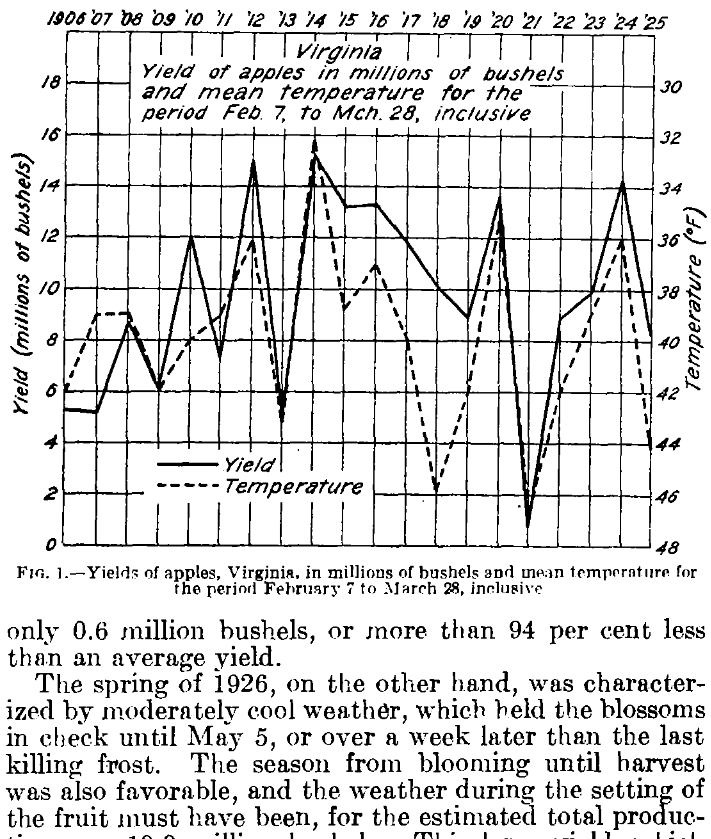

FIG. 1.—Yields of apples, Virginia, in millions of bushels and mean temperature for the period February 7 to March 28, inclusive

only 0.6 million bushels, or more than 94 per cent less than an average yield.

The spring of 1926, on the other hand, was characterized by moderately cool weather, which held the blossoms in check until May 5, or over a week later than the last killing frost. The season from blooming until harvest was also favorable, and the weather during the setting of the fruit must have been, for the estimated total production was 19.9 million bushels. This large yield, which was by far the largest of record, was the result of the cool spring and the favorable conditions until harvest.

The relation between spring temperatures and yields in this region is shown graphically on Figure 1, which is based on the total production of apples in millions of bushels from 1906 through 1925, and the spring temperatures. It will be seen that a very close relation is shown after 1911, which seems to be the boundary of "off-year" bearing. Figure 2 gives the same data for Martinsburg, W. Va., except that the yields are given in per cent of a full apple crop.

In connection with "off-year" bearing, there is a tendency of certain varieties of apples to vary their yield from year to year in such a way that a year of small yield is followed by one of larger yield, then a small yield, etc. These terms are purely relative, of course, and the smaller yield for any one year may be rather large, as compared with the average. In cases of this kind it is extremely difficult to compare apple yields with the weather as it is well known that the weather does not fluctuate in any such simple way as this. The restriction of a community to one variety, or a few varieties that have the same tendency to "off-year" bearing will cause large variations in the yield with no cause other than that inherent in the tree itself. A careful choosing of varieties of apples will largely avoid this and, as a community either discards one variety and chooses another, or new orchards come into bearing, the yields will tend to smooth themselves without great variation. Something of this kind must have occurred in Virginia, for in 1911 a marked change occurred in the total production of apples, with the yields thereafter exhibiting no apparent tendency to "off-year" bearing; the variation may be there, but so obscured by other variations as to be inobservable.

Apple production in New York State apparently was seriously affected by "off-year" bearing, as a casual sur-

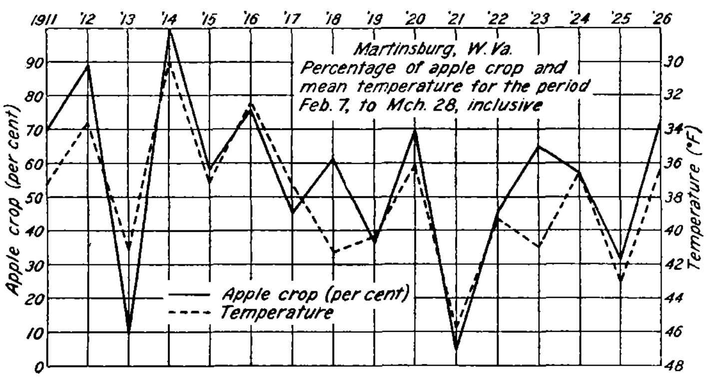

FIG. 2.—Per cent of a full apple crop, Martinsburg, W. Va., and mean temperature for the period February 7 to March 28, inclusive

vey of the data would seem to indicate a regular sequence of high and low yields. However, as some daily temperature records had already been prepared, a brief study was begun in order to determine whether or not there was any relation between yields and spring temperatures. The preliminary correlations were rather inclined to bear out the theory that any relation that might exist was obscured by "off-year" fluctuations, but as the survey enlarged, the coefficients began to be more and more significant until a conclusion could be reached that spring temperatures were of importance there also.

The data were prepared in the same manner as for Virginia, with 10 representative stations chosen throughout the fruit belt. There was, of course, some breaks in the records of the cooperative stations, but in each instance another station was taken as nearly typical of the missing one as possible. Daily temperature records were thus obtained for the 25-year period from 1901 to 1925, inclusive, and weekly mean temperatures prepared from them.

The series of correlations extended from March 1 to June 28, inclusive, and Table 1 shows the results of these. It will be noted that the temperature effect on apples in New York State is somewhat more complex than in Virginia, as there are three distinct periods of maximum importance.

TABLE 1.—*Coefficients of correlation of weekly mean temperatures with apple yields*

Beginning with—	Number of weeks						
	1	2	3	4	5	6	7
Mar. 1	−0.12	−0.22	−0.11	−0.14	−0.15	−0.19	−0.22
Mar. 8	−.18	−.08	−.13	−.14	−.20	−.22	−.29
Mar. 15	.18	−.08	−.10	−.17	−.19	−.29	−.30
Mar. 22	−.17	−.10	−.24	−.29	−.37	−.30	−.29
Mar. 29	−.09	−.25	−.28	−.38	−.36	−.24	−.16
Apr. 5	−.24	−.27	−.39	−.35	−.23	− 16	.04
Apr. 12	−.19	−.36	−.31	−.17	−.06	.14	.27
Apr. 19	−.38	−.28	−.11	.01	.22	.35	
Apr. 26	−.11	.08	.19	.35	.44		
May 3	.19	.31	.49	.52			
May 10	.25	.44	.52				
May 17	.45	.58	.50	.44	.30	.16	
May 24	.48	.41	.35	.16	−.02		
May 31	.12	.14	−.10	−.29			
June 7	.13	−.26	−.45				
June 14	−.51	−.59					
June 21	−.44						

Beginning with—	Number of weeks—Continued					
	8	9	10	11	12	13
Mar. 1	−0.27	−0.29	−0.23	−0.18	−0.08	0.01
Mar. 8	−.29	−.24	−.17	−.07	.03	
Mar. 15	−.26	−.17	−.03	.08		
Mar. 22	−.21	−.06	.09			
Mar. 29	.01	.14				
Apr. 5	.17					

The coefficients for all the early periods are small, but gradually grow larger and reach a maximum value of −0.39 for the three weeks from April 5 to April 25. The sign of the coefficient then gradually changes to positive and the values again slowly approach a maximum until the highest, +0.58, is reached for the two weeks from May 17 to May 30. The sign then changes to minus and approaches another maximum value of −0.59 for the two weeks from June 14 to June 28. This division into three distinct periods of the temperature effect is rather interesting. The last period probably coincides with that of the usual June drop; the intermediate period probably falls during the blooming time, the early period apparently has no visible phenomena in connection with it, but it may be that this is the period which coincides, or rather is comparable, with the important period in Virginia.

The coefficients of these three periods were not, in themselves, sufficiently important to justify drawing exact conclusions from them as regards the effectiveness of spring temperatures in controlling apple yields.

As the periods indicated did not overlap, temperature correlations between themselves should be comparatively small. This was found to be true, so a multiple correlation was made following the method outlined by Wallace (3). The three variables combined in this form of a correlation gave a coefficient of 0.81, which can be interpreted to mean a very high degree of relationship between the three variables and apple yields.

The equation necessary for computation of the yields was found to be: $\bar{X} = -0.490A + 0.382B - 0.605C + 49.91$.

The yields computed from this equation were found to be rather accurate, on the whole, and much closer than could be obtained from the average yield. The values of the computed and actual yields follow:

Computed and actual yields of apples in New York State

[Yields in millions of barrels]

Year	Computed yield	Actual yield	Difference
1901	6.0	3.7	2.3
1902	12.1	13.7	1.6
1903	16.2	15.3	0.9
1904	12.0	18.3	6.3
1905	8.5	7.0	1.5
1906	9.9	10.3	0.4
1907	8.3	9.3	1.0
1908	11.6	11.0	0.6
1909	7.5	8.5	1.0
1910	5.7	5.7	0.0
1911	14.6	13.0	1.6
1912	11.6	14.7	3.1
1913	6.8	6.5	0.3
1914	15.0	16.5	1.5
1915	6.6	8.5	1.9
1916	12.0	11.8	0.2
1917	11.0	5.4	5.6
1918	17.2	13.6	3.6
1919	6.7	4.8	1.9
1920	14.1	15.7	1.6
1921	6.3	4.5	1.8
1922	10.8	12.0	1.2
1923	8.0	8.3	0.3
1924	8.1	7.3	0.8
1925	7.9	10.8	2.9
Average	10.2	10.2	1.8

It will be seen that there are several instances where the computed yields show large deviations from the true yield, but these are not as large as their deviation from the average yield. The standard deviation of yield is 4.05 million barrels and that of actual from computed is 2.33 million barrels, or a reduction of 42.5 per cent.

SUMMARY

The data on hand are, of course, rather limited and can not take into account all possible influences on yield. It was planned originally to demonstrate that apple yields were largely affected by spring temperatures and this seems to be proven beyond a reasonable doubt.

There are, of course, other factors which influence yield, but in a study of this type for an entire State they are too varied to be included and an attempt to combine all possible influences, if known, would necessarily be tremendously bulky and take an amount of time entirely out of comparison with the results obtained.

Single orchards, if complete data could be obtained, would produce results of more significance than those for a whole State. The State data must necessarily be less complete and more difficult of access even when there are more or less detailed reports. Using the data before mentioned the results are very satisfactory in that they conclusively demonstrate that the one factor of major importance is spring temperatures.

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ON THE MEASURE OF CORRELATION

By GILBERT T. WALKER

[Imperial College of Science and Technology, South Kensington, London, S. W. 7, November 1, 1927]

There has of late been a welcome recognition of the services that can be rendered to meteorology by statistical methods; but associated with some of the recent theoretical discussion there have been elements which appear to me unsound and I would ask permission to make some remarks on a theorem which is attributed to W. H. Dines.

1. The authoritative enunciation of the theorem is that contained in the Méteorological Magazine.[1]

"If there is a cause A and a result M with a correlation r between them, then in the long run A is responsible for r^2 of the variation of M."

On the other hand, working in India in regrettable ignorance of the classical literature of the subject, I was led to develop the ordinary regression equations from a definition of the correlation coefficient between two quantities as "the proportionate extent to which the variations of each are determined by, or related to, those of the other." [2]

2. It might at first sight appear that so fundamental a discrepancy must rest on a wide difference of terminology; but this can scarcely be the case. If the departures of M and of A are denoted by x_0 and x_1, and their standard deviations or "square-means" by σ_0 and σ_1, we may denote x_0/σ_0 and x_1/σ_1, "the proportional departures," by z_0 and z_1.

Then the ordinary regression equation is

$$x_0 = \frac{r\sigma_0}{\sigma_1}x_1 + b$$

where b is independent of x_1, or $z_0 = rz_1 + d$, where d is independent of z_1.

That part of the variation of M which is related to, or controlled by, A is, by (1), $r\ \sigma_0\ x_1/\sigma_1$; and it is important to note that this value is accepted by both parties in this discussion. In the last paragraph of the statement of the Meteorological Magazine we read "the average contribution of a to m, i. e., the average value of $r\sigma_m\left[r\frac{m}{\sigma_m}+y\right]$"; and, by equation (7) there, this is equal to $r\sigma_m\left[\frac{a}{\sigma_m}\right]$; in our notation this is $r\sigma_0\frac{x_1}{\sigma_1}$, which bears to σ_0 the ratio rz_1. We may note that this interpretation is also accepted by Krichewsky,[3] who writes in his (6a) the regression equation for two variables as $z_0 = \beta_{01}z_1$ and replaces this in his (11) by $z_0 = r_{01}\beta_{01}z_1$. He then defines E_{01} as "that part of the variation of z_0 for which the variable z_1 is responsible in the long run . . " and takes E_{01} as $r_{01}\beta_{01}$.

Now, as stated below, I do not agree with the substitution of $\beta_{01}z_0$ for z_1, but the fact remains that Krichewsky regards something equal to $\beta_{01}z_1$ as the part for which z_1 is responsible.

3. Now x_1 is a quantity obeying the same error law of distribution as x_0, its standard derivation being σ_1 corresponding to σ_0 for x_0; so just as the values of z_0 obey the error law of distribution and have a standard deviation of unity, the values of rz_1 will obey the error law and have a standard deviation of r. To say that in the long run these values of rz_1 are r^2 times those of z_0 appears to me definitely because mathematically, incorrect. It must

[1] February, 1921, p. 21.
[2] Indian Meteorological Memoirs, Vol. xx, Pt. 6, p. 120, 1909.
[3] "Interpretation of correlation coefficients." Physical Dept. Paper No. 22, Cairo, 1927.